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Charm nonleptonic decays and final state interactions

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ABSTRACT

A global previous analysis of two-body nonleptonic decays of D mesons has been extended to the decays involving light scalar mesons. The allowance for final state interaction also in nonresonant channels provides a fit of much improved quality and with less symmetry breaking in the axial charges. We give predictions for about 50 decay branching ratios yet to be measured. We also discuss long distance contributions to the difference $\Delta\Gamma$ between the D_S and D_L widths.

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A theoretical description of exclusive nonleptonic decays of charmed hadrons based on general principles is not yet possible. Even if the short distance effects due to hard gluon exchange can be resummed and the effective hamiltonian has been constructed at next-to-leading order [1], the evaluation of its matrix elements requires nonperturbative techniques. A classic analysis based on QCD sum rules has been presented in three papers by Blok and Shifman [2], but only the general trends were reproduced: the agreement with present data is poor at a quantitative level. Waiting for future progress in lattice QCD calculations one has to rely on approximate methods and on models.

We recently presented [3] one such model, based on the factorized approximation, with annihilation terms and rescattering effects due to resonances coupled to the final states, that has been rather successful in describing the bulk of the experimental data. Its main shortcoming was, in our opinion, the large flavour SU(3) breaking in the axial charges forced by the fitting of the data on decay rates to final states with one pseudoscalar and one vector meson (PV).

In this letter we modify the previous approach, inserting rescattering corrections also in nonresonant channels. Moreover, we include the decays to final states containing one of the lowest mass scalar mesons (S), $f_0(980)$ and $a_0(980)$, that are connected through rescattering effects to the previously considered PV final states. In this way, we are able to obtain a much better fit of the experimental data, while keeping the SU(3) breaking in the axial charges at a smaller and more acceptable level.

The scattering phase shifts in nonresonant channels were neglected in [3]. For decays to PP final states this is essentially correct, given that only one nonresonating phase, corresponding to the $\underline{27}$ representation, is involved and of course the final rates only depend on the phase shift differences. In the case of PV final states, on the other hand, many different SU(3) representations are present: to minimize the number of parameters, we only include a nonzero phase shift for the $\underline{27}$ (besides the resonant $\underline{8}_F$) and keep the others to zero. The $\underline{27}$ phase shift is most welcome, especially to obtain a better fit for $D^+ \rightarrow PV$ Cabibbo-allowed decays. We admit two different values for the phase shift at the different energies, corresponding to the masses of D and of D_s : the fitted values are $\delta_{27}(m_D) = 47.4^\circ$ and $\delta_{27}(m_{D_s}) = 59^\circ$, reasonably similar to each other, although maybe larger than expected.

The nature of the scalar resonances, $f_0(980)$ and $a_0(980)$, has been discussed for quite a long time. They do not look like the members of a normal nonet, in that the f_0 is strongly coupled to $K\bar{K}$, and could be for this reason identified with an $s\bar{s}$ state, but it is degenerate in mass with the isovector a_0 . Moreover, the strange scalar states lie quite a bit higher. For these reasons, it has been suggested that the f_0 and a_0 are essentially $K\bar{K}$

molecules and are made therefore of two quarks and two antiquarks, *i.e.* an $s\bar{s}$ pair plus a light $q\bar{q}$ pair [4], [5]. In charmed meson decays, both $D_s^+ \rightarrow f_0\pi^+$ and $D^0 \rightarrow f_0K_S$ have been observed experimentally [6], [7], [8]. In the factorized approximation, one would have for the decay amplitudes prior to rescattering corrections:

$$\begin{aligned}
\mathcal{A}_w(D_s^+ \rightarrow f_0\pi^+) &= \\
&= -\frac{G_F}{\sqrt{2}} U_{ud} U_{cs}^* (C_2 + \xi C_1) \langle f_0 | (A_s^c)_\mu | D_s^+ \rangle \langle \pi^+ | (A_u^d)^\mu | 0 \rangle \\
&= -\frac{G_F}{\sqrt{2}} U_{ud} U_{cs}^* (C_2 + \xi C_1) f_\pi \langle f_0 | \partial^\mu (A_s^c)_\mu | D_s^+ \rangle, \\
\mathcal{A}_w(D^0 \rightarrow f_0\bar{K}^0) &= \\
&= -\frac{G_F}{\sqrt{2}} U_{ud} U_{cs}^* (C_1 + \xi C_2) \langle f_0 | (A_u^c)_\mu | D^0 \rangle \langle \bar{K}^0 | (A_s^d)^\mu | 0 \rangle \\
&= -\frac{G_F}{\sqrt{2}} U_{ud} U_{cs}^* (C_1 + \xi C_2) f_K \langle f_0 | \partial^\mu (A_u^c)_\mu | D^0 \rangle.
\end{aligned} \tag{1}$$

In (1) C_i are the Wilson coefficients in the effective hamiltonian, ξ is the color screening parameter (that should be equal to $1/N_c$ if the factorization approach were exact), the axial currents are denoted by $(A_q^a)^\mu \equiv \bar{q}' \gamma^\mu \gamma_5 q$ and we neglected possible annihilation contributions. The observation of the decay $D_s^+ \rightarrow f_0\pi^+$ would imply the $s\bar{s}$ nature for f_0 , while $D^0 \rightarrow f_0\bar{K}^0$ points to a nonstrange composition.

Following the suggestion of [5] we consider f_0 and a_0 as cryptoexotic two-quark plus two-antiquark states and attribute them to (incomplete) $\underline{8}$ and $\underline{1}$ SU(3) representations $|a_0\rangle \in |\underline{8}\rangle$, $|f_0\rangle \in \sqrt{\frac{1}{3}}|\underline{8}\rangle + \sqrt{\frac{2}{3}}|\underline{1}\rangle$. We then define

$$\begin{aligned}
\langle f_0 | \partial^\mu (A_s^c)_\mu | D_s^+ \rangle &= (M_{D_s}^2 - M_{f_0}^2) \frac{a_S}{(1 - q^2/M_{D_s}^2)}, \\
\langle f_0 | \partial^\mu (A_u^c)_\mu | D^0 \rangle &= (M_D^2 - M_{f_0}^2) \frac{a_S}{\sqrt{2}(1 - q^2/M_D^2)}.
\end{aligned} \tag{2}$$

The axial charge a_S is a parameter to be fitted. The result is $a_S \simeq 0.39$, smaller – as expected – than the corresponding axial charges for D transitions to vector mesons.

Our model also predicts charmed meson decays to states including the $a_0(980)$ meson and Cabibbo suppressed decays to PS , not yet observed. The amplitudes in factorized approximation are easily obtained, and the relevant form factors are all expressed in terms of the parameter a_S : as an example,

$$\langle a_0^0 | \partial^\mu (A_d^c)_\mu | D^+ \rangle = - (M_D^2 - M_{a_0}^2) \frac{a_S}{\sqrt{2}(1 - q^2/M_D^2)}. \tag{2'}$$

We describe now in more detail the procedure followed to include final state interactions. Defining as \mathcal{B} the decay amplitude including the phase space factor, *i.e.* $\mathcal{B}_w = \mathcal{A}_w \sqrt{p / (8 \pi m_D^2)}$ where p is the momentum of the final particles in the D rest frame, we have for $D \rightarrow PV$ (PS) decays

$$\begin{aligned}\mathcal{B}(D \rightarrow V_h P_k) &= \mathcal{B}_w(D \rightarrow V_h P_k) + c_{hk} [\exp(i\delta_8) - 1] A_T^8 + d_{hk} [\exp(i\delta_{27}) - 1] A_T^{27}, \\ \mathcal{B}(D \rightarrow S_h P_k) &= \mathcal{B}_w(D \rightarrow S_h P_k) + x_{PS} \tilde{c}_{hk} [\exp(i\delta_8) - 1] A_T^8 + \\ &\quad + y_{PS} \tilde{d}_{hk} [\exp(i\delta_{27}) - 1] A_T^{27},\end{aligned}\tag{3}$$

where

$$\begin{aligned}A_T^8 &= \frac{\sum_{h'k'} c_{h'k'} \mathcal{B}_w(D \rightarrow V_{h'} P_{k'}) + x_{PS} \sum_{h''k''} \tilde{c}_{h''k''} \mathcal{B}_w(D \rightarrow S_{h''} P_{k''})}{\sum_{h'k'} |c_{h'k'}|^2 + x_{PS}^2 \sum_{h''k''} |\tilde{c}_{h''k''}|^2}, \\ A_T^{27} &= \frac{\sum_{h'k'} d_{h'k'} \mathcal{B}_w(D \rightarrow V_{h'} P_{k'}) + y_{PS} \sum_{h''k''} \tilde{d}_{h''k''} \mathcal{B}_w(D \rightarrow S_{h''} P_{k''})}{\sum_{h'k'} |d_{h'k'}|^2 + y_{PS}^2 \sum_{h''k''} |\tilde{d}_{h''k''}|^2}.\end{aligned}\tag{4}$$

In (3) and (4) c_{hk} (d_{hk}) are the PV couplings to $\underline{8}_F$ (27), multiplied by a $(p/M_\rho)^{\frac{3}{2}}$ kinematical factor. This p dependence must be present in the \mathcal{B} amplitudes and, as in [3], we include it in the coefficients in order to automatically decouple the channels below threshold. The PS couplings ¹ to $\underline{8}_D$ (27), multiplied by their kinematical factor (in this case $(p/M_\rho)^{\frac{1}{2}}$), are denoted \tilde{c}_{hk} (\tilde{d}_{hk}).

We note that the phase shift δ_8 is determined by the parameters of the resonance \tilde{P} appropriate to the decay channel considered ($\tilde{P} = K(1830)$ or $\pi(1770)$), as follows

$$\sin \delta_8 \exp(i\delta_8) = \frac{\Gamma(\tilde{P})}{2(M_{\tilde{P}} - M_D) - i\Gamma(\tilde{P})}.\tag{5}$$

In the isoscalar case, $\delta_8^{I=0}$ is a free parameter instead.

The parameters x_{PS} and y_{PS} are connected with the mixing between PV and PS channels. The representations $\underline{8}_F$ (for PV) and $\underline{8}_D$ (for PS) have the same parity and charge conjugation and may therefore naturally mix, $x_{PS} \neq 0$. The two 27 representations have opposite charge conjugation; the zero hypercharge sectors cannot mix if isospin is a good symmetry, while the $Y=\pm 1$ terms may be mixed with *opposite* mixing angles y_{PS} (this is an SU(3) violating effect: SU(3) symmetry requires *equal* mixing angles for any Y value). We required in the fit $|y_{PS}| \leq |x_{PS}|$.

We have to face the problem of enforcing orthogonality between the resonant $\underline{8}$ and the non-resonant 27 channels. These would be orthogonal in the SU(3) symmetric limit,

¹ For the couplings of the singlet parts of f_0 , η and η' we adopt nonet symmetry.

but they are not. For the PS channels, the scalar multiplet is incomplete and therefore the orthogonality is badly broken. Even for the PV channels the cancellations that would give orthogonality do not actually take place, since we included in the rescattering coefficients the kinematical factors. For D^0 Cabibbo allowed decays one has $\sum_{h''k''} \tilde{c}_{h''k''} \tilde{d}_{h''k''} \simeq 0.16$ and $\sum_{h'k'} c_{h'k'} d_{h'k'} \simeq 0.008$.

The difficulty may be nicely overcome taking advantage of the mixing between PV and PS final states. The orthogonality requirement

$$\sum_{h'k'} c_{h'k'} d_{h'k'} + x_{PS} y_{PS} \sum_{h''k''} \tilde{c}_{h''k''} \tilde{d}_{h''k''} = 0 \quad (6)$$

establishes a relation between x_{PS} and y_{PS} , so that only one of them remains as a free parameter. The best fit values are $x_{PS} \simeq 0.25$ and

$$y_{PS} = \begin{cases} \mp 0.20, & \text{for } D \text{ Cabibbo allowed (doubly-forbidden) decays;} \\ 0.00, & \text{for } D_s \text{ Cabibbo allowed and } D \text{ first-forbidden decays;} \\ +0.19, & \text{for } D_s \text{ first-forbidden decays.} \end{cases}$$

We briefly recall now the aspects of [3] that are not modified in the present approach. For the evaluation of the weak decay amplitudes \mathcal{A}_w we use the factorization approximation and a pole model for the form factors, as in eqs. (1), (2). The weak vector charges are assumed SU(3) symmetric: their value, 0.79, is taken from the experimental results for $D \rightarrow K e \nu$. For the axial charges we allow some SU(3) breaking, and let them vary in the range $0.8 \div 0.9$ independently. The decays to final states including η or η' mesons have been treated following the approach of D'yakonov and Eides [9]: the η - η' mixing angle is therefore fixed to -10° . For the decays to PP and PV channels we also consider the contribution from annihilation (or W -exchange) diagrams: the relevant matrix elements of the divergences of weak currents are given in terms of two parameters to be fitted, W_{PP} and W_{PV} , with [3]

$$\begin{aligned} \langle K^- \pi^+ | \partial^\mu (V_s^d)_\mu | 0 \rangle &= i (m_s - m_d) \frac{M_D^2}{f_D} W_{PP}, \\ \langle K^- \rho^+ | \partial^\mu (A_s^d)_\mu | 0 \rangle &= - (m_s + m_d) \frac{2 M_\rho}{f_D} \epsilon^* \cdot p_K W_{PV}. \end{aligned} \quad (7)$$

The final state interactions for the PP channels are dominated by the scalar resonances. Only one of them, the strange $K_0^*(1950)$, has been observed [10] in the interesting mass region. In [3] we assumed the existence of a nearby isovector resonance a_0 and we estimated its mass from the equispacing formula

$$M_{a_0}^2 = M_{K_0^*}^2 - M_K^2 + M_\pi^2. \quad (8)$$

In the fit we allowed the mass, width and branching ratio in the $K\pi$ channel ² of the K_0^* resonance to vary within the experimental bounds. From their best fit values (1930 MeV, 300 MeV and 63.5%, respectively) we get $M_{a_0} = 1870$ MeV and $\Gamma_{a_0} = 299.4$ MeV.

In the nonstrange isoscalar case, only relevant for D^0 first–forbidden decays, the situation is complicated by the possibility of singlet–octet mixing of not yet established resonances. The number of parameters (mixing angles, masses and coupling constants) is *a priori* quite large. We imposed the decoupling of the higher mass resonance from the $\pi\pi$ channel, which together with the requirement of orthogonality reduces the number of new parameters to two: the mixing angle ³ ϕ and the difference $\Delta^2 = m_{f'_0}^2 - m_{f_0}^2$ of the mass squared (see [3] for details). Using the fitted parameters, the masses and widths of the two scalar isoscalar resonances are $(M_{f_0}, \Gamma_{f_0}) = (1789, 354)$ MeV and $(M_{f'_0}, \Gamma_{f'_0}) = (2127, 328)$ MeV.

We performed a least square fit with 15 parameters to the 49 data points or experimental bounds for the branching ratios. The results are presented in Tables 1 to 4, together with predictions for the channels not yet measured. The values of the eleven parameters already used in the previous fits are now: $\xi = 0.015$, $a_{cu} = a_{cd} = 0.9$, $a_{cs} = 0.8$, $W_{PP} = -0.269$, $W_{PV} = 0.270$, $M_{K_0^*} = 1930$ MeV, $\Gamma_{K_0^*} = 300$ MeV, $r = -0.86$, $\phi = 47.7^\circ$, $\Delta = 1149.4$ MeV and $\delta_8^{I=0} = 236.5^\circ$. In [3] the axial charges were $a_{cu} = a_{cd} = 1.0$ and $a_{cs} = 0.59$, while the other parameters are not changed much. We list again the four “new” parameter values: $\delta_{27}(m_D) = 47.4^\circ$, $\delta_{27}(m_{D_s}) = 59^\circ$, $a_S = 0.390$ and $x_{PS} = 0.249$. The values of decay constants, quark masses and resonance parameters not explicitly mentioned are identical to the values given in [3].

The total χ^2 is 70.3 (of which 6.2 from two Cabibbo doubly–forbidden decays and two decays to PS final states, not included in the previous fits). In ref. [3], χ^2 was 90 for 45 data points and 11 parameters. A more detailed comparison of the two fits is shown in Table 5. We note that the most remarkable improvement occurs for the $D^+ \rightarrow PV$ decays: it is mainly due to rescattering in the exotic $I = \frac{3}{2}$ channel, that is the only rescattering effect present in the Cabibbo–allowed D^+ decay amplitudes. The worst single point in the fit of ref. [3], the branching ratio $B(D^+ \rightarrow \overline{K}^{*0}\pi^+)$ (that was $B_{th} = 0.64$ % versus

² Actually, the parameter to be fitted is the ratio $r = g_{818}/g_{888}$, where g_{818} is the SU(3) invariant coupling of the octet of scalar resonances to a singlet and an octet of pseudoscalar mesons and g_{888} is the coupling to two pseudoscalar octets [3]. Nonet symmetry corresponds to $r = 1$. The branching ratio is a quadratic function of r .

³ Denoting by $|f_0\rangle$ the lower mass state, we define $|f_0\rangle = \sin\phi |f_8\rangle + \cos\phi |f_1\rangle$, $|f'_0\rangle = -\cos\phi |f_8\rangle + \sin\phi |f_1\rangle$.

$B_{exp} = 2.2 \pm 0.4$ %), is now fitted quite well, $B_{th} = 2.47$ %. This overcompensates the slightly worse fit for the decay $D^+ \rightarrow K_S \rho^0$: $B_{th} = 5.60$ % now (5.28 % in [3]) versus $B_{exp} = 3.3 \pm 1.25$ %. The greater freedom provided by the presence of the new parameters δ_{27} allows the reduction of the SU(3) breaking in the axial constants $a_{cu} = a_{cd}$ and a_{cs} , that we imposed not to differ by more than 0.1 in this work. It also allows an apparently minor change in the annihilation parameters and in the parameter ξ , which now happens to be small and positive: this has the effect of improving considerably the success of the fit also for the decay $D^+ \rightarrow K_S \pi^+$: $B_{th} = 1.35$ % (it was 1.08 %) versus $B_{exp} = 1.37 \pm 0.15$ %. A considerable improvement also occurs for the Cabibbo forbidden decay $D^+ \rightarrow K^+ \bar{K}^{*0}$: $B_{th} = 0.38$ % (it was 0.25 %) versus $B_{exp} = 0.51 \pm 0.10$ %.

Concerning the decay rates of D_s^+ and D^0 , the quality of the present fit is comparable to the fit in ref. [3]. In particular, for $D^0 \rightarrow \bar{K}^{*0} \eta$ and $D_s^+ \rightarrow \rho^+ \eta'$ the results are still unsatisfactory (more than three standard deviations lower than the data points). Neither annihilation contributions, nor final state interactions were present for channels with positive G -parity and $I = 1$, like $\rho^+ \eta'$, in [3]. In this fit the exotic rescattering affects these channels, giving for instance a nonzero branching ratio for the decay $D_s^+ \rightarrow \omega \pi^+$; however, it only slightly lowers (going in the wrong direction) the theoretical prediction for $D_s^+ \rightarrow \rho^+ \eta'$. It might be possible to attribute the discrepancy ⁴ to an annihilation contribution, not taken into account here, through the glue components in η' and η [12].

Two out of four data points not included in the fit of [3] are very well fitted, but the predictions for the other two are not equally satisfactory. The amplitude for the decay $D^0 \rightarrow f_0 K_S$ is colour suppressed and is further decreased by the rescattering effects in our model: the theoretical value is therefore smaller than the experimental datum. The doubly-forbidden decay $D^+ \rightarrow K^+ \phi$ can only proceed through annihilation or rescattering: also in this case, the theoretical value is considerably lower than experiment. It should be noted, however, that recent data from E791 collaboration [13] do not observe a signal in this channel and establish an upper bound slightly less than the central value of E691 [14], reported in Table 1.

As to the predictions for not yet measured decay branching ratios, the largest among them refers to the Cabibbo first-forbidden decay $D^+ \rightarrow \bar{K}^0 K^{*+}$. The decay amplitude is colour favoured in this case, and it has a small interfering annihilation contribution instead of the larger, although colour suppressed, contribution present in Cabibbo allowed D^+ decays. The same is true for the process $D^+ \rightarrow \bar{K}^0 K^+$. The rescattering effects

⁴ The large branching ratio for $D_s^+ \rightarrow \rho^+ \eta'$ is difficult to reproduce in many a model, see also [11].

decrease the decay rate for $\overline{K}^0 K^+$ (which is in very good agreement with experiment) and increase instead the rate for $\overline{K}^0 K^{*+}$. The next bigger prediction, for $B(D_s^+ \rightarrow K^0 \rho^+)$, deserves a similar comment: it is also increased ($\sim 20\%$) by rescattering effects. Among Cabibbo doubly-forbidden decays, we predict the largest branching fractions ($\sim 5 \cdot 10^{-4}$) for the decays $D^+ \rightarrow K^{+(*)} \pi^0$. A check for the assumption we made on the scalar particles will be the observation of decays with $a_0(980)$ production. The largest prediction for not yet observed PS decay channels is $B(D^+ \rightarrow a_0^+ K_S) = 0.32 \%$.

We will not present here the predictions for CP violating decay asymmetries, that depend strongly on the rescattering phases: therefore, they remain similar to those previously published ⁵ for the PP final states, and differ appreciably in some cases for the PV channels. The largest asymmetries ($\sim -3 \cdot 10^{-3}$) are now predicted in the decays $D^+ \rightarrow \rho^+ \eta$ and $D^0 \rightarrow \omega \eta'$: they are entirely due to exotic rescattering, and were therefore zero in [3]. The branching ratios of these decays are however small, so that the best candidate should be given by the decays $D^+ \rightarrow \rho^0 \pi^+$ and $D^- \rightarrow \rho^0 \pi^-$, the predicted asymmetry being approximately $-2 \cdot 10^{-3}$.

A considerable interest has been recently devoted to the interplay of $D^0 - \bar{D}^0$ mixing and doubly Cabibbo forbidden amplitudes in the time evolution for D^0 decays [15]. Particular attention has been given to a term proportional to ΔM and providing linear correction to the exponential decay, present as a consequence of CP violation and/or final state interactions, as a possible source of information on “new physics”. A term proportional to $\Delta \Gamma$ is also present. The short distance contributions predicted by the standard model are very small for both ΔM and $\Delta \Gamma$ [16]. It was suggested that the mixing may be dominated by long distance (hadronic) contributions [17] that could result in mixing parameters $x = \Delta M / \Gamma$ and $y = \Delta \Gamma / (2 \Gamma)$ as large as 10^{-2} , although this was later criticized [18].

In our model, we can make an estimate of the long distance contribution to $\Delta \Gamma$ coming from the two-body states that we included in our fit. This quantity should vanish in the $SU(3)$ limit, through an exact cancellation of the contribution of Cabibbo allowed and doubly-forbidden transitions with the contribution of once-forbidden decays [17]. In the presence of $SU(3)$ breaking the cancellation is however not complete. As a consequence, our prediction for $\Delta \Gamma$ is subject to a large uncertainty; on the other hand, it is to be noted that the prediction is independent on the rescattering, provided that, as we impose, the sum of the branching ratios remains the same before and after rescattering corrections.

⁵ We remark that all the asymmetries reported in Table V of ref. [3] in correspondence to D^0 decays have a wrong sign. The signs for the charged D decay asymmetries are correct.

We have ($|\bar{D}^0\rangle = CP |D^0\rangle$)

$$\Gamma_{12} = \sum_{|f\rangle} \mathcal{B}^*(D^0 \rightarrow f) \mathcal{B}(\bar{D}^0 \rightarrow f) \simeq (1.5 + i0.0014) 10^{-3} \Gamma_{D^0} \quad (9)$$

In (9) the sum has been approximated including only the contributions of PP ($2/3$), PV ($1/3$) and PS (~ 0) final states. Note that the contribution to Γ_{12}/Γ_{D^0} coming from Cabibbo first-forbidden decays alone is $35.2 \cdot 10^{-3}$, showing that the $SU(3)$ cancellation is still rather effective. Although larger than the short-distance prediction, our estimate is much smaller than the present [6] experimental bound $|y| = |\Gamma_{12}| / \Gamma_{D^0} \leq 0.08$. The positive sign of the real part of Γ_{12} means (if taken seriously) that the shorter lifetime state, D_S^0 , decays dominantly into CP -even final states, similarly to the neutral K mesons.

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f_i	$B_{exp}(D^+ \rightarrow f_i)$	B_{th}	f_i	$B_{exp}(D^+ \rightarrow f_i)$	B_{th}
$K_S \pi^+$	1.37 ± 0.15	1.35	$\pi^+ \pi^0$	0.25 ± 0.07	0.19
$K_L \pi^+$	—	1.70	$\pi^+ \eta$	0.75 ± 0.25	0.34
$\overline{K}^{*0} \pi^+$	2.2 ± 0.4	2.47	$\pi^+ \eta'$	< 0.9	0.73
$K_S \rho^+$	3.30 ± 1.25	5.60	$\overline{K}^0 K^+$	0.78 ± 0.17	0.81
$K_L \rho^+$	—	6.30	$\rho^0 \pi^+$	< 0.14	0.13
$a_0^+ K_S$	—	0.32	$\rho^+ \pi^0$	—	0.44
$a_0^+ K_L$	—	0.24	$\rho^+ \eta$	< 1.2	0.013
$K^+ \pi^0$	—	0.056	$\rho^+ \eta'$	< 1.5	0.12
$K^+ \eta$	—	0.018	$\omega \pi^+$	< 0.7	0.019
$K^+ \eta'$	—	0.031	$\phi \pi^+$	0.67 ± 0.08	0.61
$K^{*0} \pi^+$	—	0.019	$\overline{K}^0 K^{*+}$	—	1.71
$K^{*+} \pi^0$	—	0.048	$\overline{K}^{*0} K^+$	0.51 ± 0.10	0.38
$K^{*+} \eta$	—	0.030	$f_0 \pi^+$	—	0.028
$K^{*+} \eta'$	—	0.0002	$a_0^0 \pi^+$	—	0.059
$K^+ \rho^0$	—	0.030	$a_0^+ \pi^0$	—	0.012
$K^+ \omega$	—	0.021	$a_0^+ \eta$	—	0.074
$K^+ \phi$	0.039 ± 0.022	0.0051	$K^+ f_0$	—	0.0023
			$K^+ a_0^0$	—	0.0062

TABLE 1

Branching ratios for D^+ nonleptonic decays.

[Experimental data and 90% c.l. upper bounds from ref. [6]]

f_i	$B_{exp}(D_s^+ \rightarrow f_i)$	B_{th}	f_i	$B_{exp}(D_s^+ \rightarrow f_i)$	B_{th}
$K_S K^+$	1.75 ± 0.35	2.37	$K^+ \pi^0$	—	0.14
$K_L K^+$	—	2.09	$K^+ \eta$	—	0.28
$\pi^+ \eta$	1.90 ± 0.40	1.23	$K^+ \eta'$	—	0.44
$\pi^+ \eta'$	4.7 ± 1.4	5.39	$K^0 \pi^+$	< 0.7	0.40
$\rho^+ \eta$	10.0 ± 2.2	7.49	$K^{*+} \pi^0$	—	0.044
$\rho^+ \eta'$	12.0 ± 3.0	2.41	$K^+ \rho^0$	—	0.29
$\bar{K}^{*0} K^+$	3.3 ± 0.5	3.96	$K^{*+} \eta$	—	0.18
$K_S K^{*+}$	2.1 ± 0.5	1.87	$K^{*+} \eta'$	—	0.025
$K_L K^{*+}$	—	2.13	$K^+ \omega$	—	0.15
$\phi \pi^+$	3.5 ± 0.4	4.08	$K^+ \phi$	< 0.25	0.018
$\omega \pi^+$	< 1.7	0.26	$K^{*0} \pi^+$	—	0.29
$\rho^0 \pi^+$	< 0.28	0.24	$K^0 \rho^+$	—	1.39
$\rho^+ \pi^0$	—	0.24	$f_0 K^+$	—	0.069
$f_0 \pi^+$	1.0 ± 0.4	1.06	$a_0^+ K^0$	—	0.003
$a_0^+ \eta$	—	0.007	$a_0^0 K^+$	—	0.007
$a_0^+ \eta'$	—	0.002	$K^{*0} K^+$	—	0.008

TABLE 2

Branching ratios for D_s^+ nonleptonic decays.

[Experimental data and 90% c.l. upper bounds from ref. [6]]

f_i	$B_{exp}(D^0 \rightarrow f_i)$	B_{th}	f_i	$B_{exp}(D^0 \rightarrow f_i)$	B_{th}
$K^- \pi^+$	4.01 ± 0.14	4.04	$\pi^0 \eta$	—	0.052
$K_S \pi^0$	1.02 ± 0.13	0.72	$\pi^0 \eta'$	—	0.16
$K_L \pi^0$	—	0.53	$\eta \eta$	—	0.088
$K_S \eta$	0.34 ± 0.06	0.42	$\eta \eta'$	—	0.18
$K_L \eta$	—	0.31	$\pi^0 \pi^0$	0.088 ± 0.023	0.110
$K_S \eta'$	0.83 ± 0.15	0.78	$\pi^+ \pi^-$	0.159 ± 0.012	0.159
$K_L \eta'$	—	0.61	$K^+ K^-$	0.454 ± 0.029	0.446
$\bar{K}^{*0} \pi^0$	3.0 ± 0.4	3.49	$K^0 \bar{K}^0$	0.11 ± 0.04	0.098
$K_S \rho^0$	0.55 ± 0.09	0.47	$\omega \pi^0$	—	0.014
$K_L \rho^0$	—	0.33	$\rho^0 \eta$	—	0.020
$K^{*-} \pi^+$	4.9 ± 0.6	4.85	$\rho^0 \eta'$	—	0.008
$K^- \rho^+$	10.4 ± 1.3	11.02	$\omega \eta$	—	0.20
$\bar{K}^{*0} \eta$	1.9 ± 0.5	0.37	$\omega \eta'$	—	0.0001
$\bar{K}^{*0} \eta'$	< 0.11	0.004	$\phi \pi^0$	—	0.11
$K_S \omega$	1.0 ± 0.2	0.88	$\phi \eta$	—	0.090
$K_L \omega$	—	0.80	$K^{*0} \bar{K}^0$	< 0.08	0.064
$K_S \phi$	0.415 ± 0.060	0.40	$\bar{K}^{*0} K^0$	< 0.15	0.062
$K_L \phi$	—	0.42	$K^{*+} K^-$	0.34 ± 0.08	0.43
$f_0 K_S$	0.23 ± 0.10	0.037	$K^{*-} K^+$	0.18 ± 0.10	0.30
$f_0 K_L$	—	0.031	$\rho^+ \pi^-$	—	0.69
$a_0^0 K_S$	—	0.109	$\rho^- \pi^+$	—	0.57
$a_0^0 K_L$	—	0.083	$\rho^0 \pi^0$	—	0.12
$a_0^+ K^-$	—	0.078			

TABLE 3

Branching ratios for D^0 Cabibbo allowed and first-forbidden decays.

[Experimental data and 90% c.l. upper bounds from ref. [6]]

f_i	$B_{exp}(D^0 \rightarrow f_i)$	B_{th}	f_i	$B_{exp}(D^0 \rightarrow f_i)$	B_{th}
$f_0 \pi^0$	—	0.0006	$K^+ \pi^-$	0.031 ± 0.014	0.033
$f_0 \eta$	—	0.004	$K^{*0} \pi^0$	—	0.0039
$a_0^0 \pi^0$	—	0.011	$K^{*+} \pi^-$	—	0.035
$a_0^0 \eta$	—	0.015	$K^+ \rho^-$	—	0.025
$a_0^+ \pi^-$	—	0.003	$K^{*0} \eta$	—	0.009
$a_0^- \pi^+$	—	0.070	$K^{*0} \eta'$	—	$\sim 10^{-5}$
			$a_0^- K^+$	—	0.004

TABLE 4

Branching ratios for D^0 Cabibbo first- and doubly-forbidden decays.
[Experimental data from ref. [6]]

Decays	# data	χ^2 (ref. [3])	χ^2 (This work)
$D^+ \rightarrow PP$	5	9.56	5.34
$D^+ \rightarrow PV$	8	29.55	8.46
$D_s^+ \rightarrow PP$	4	8.79	7.10
$D_s^+ \rightarrow PV$	8	15.35	17.64
$D^0 \rightarrow PP$	8	8.44	8.43
$D^0 \rightarrow PV$	12	18.35	17.17

TABLE 5

Comparison of our results with the fit of ref. [3].
Only Cabibbo-allowed and first-forbidden decays are included.